Non-Toxic Soil Thickeners for Reducing Mudslide Intensity

A Senior Project
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Bachelor of Science

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Abstract

Non-toxic food thickeners were investigated as a solution for thickening mud to mitigate the effects of mudslides. All soil was obtained from a site on the California Polytechnic State University campus where a mudslide occurred in 2017. Guar gum was mixed into the soil at 1 wt% and 10 wt% of the moisture content in the soil. Whey protein was mixed into the soil at 2 wt% and 19 wt% of the moisture content in the soil. The soils' liquid limit was found using the Casagrande cup testing method. Liquid limit testing indicated that thickeners raised the liquid limit, most significantly the higher concentration of guar gum. The viscosities of the treated and untreated soils were found using a viscometer. Viscosity measurements indicated that 10 wt% guar gum had the greatest immediate thickening effect, while after 72 hours, 19 wt% whey had the highest viscosity. Soil and thickener interactions were examined using scanning electron microscopy (SEM). Tests for soil toxicity were conducted by seeding annual ryegrass in the soils, and comparing the biomass of the ryegrass grown in each soil treatment, as well as measuring the Degrees Brix of the grasses. The soil toxicity showed that all treatments were non-toxic to ryegrass, with a low concentration of whey protein having an unintended fertilizing effect.

1. Introduction

The recent mudslides caused by rain storms after the Thomas Fire in Montecito, California, took 23 lives and devastated communities, homes, and infrastructure worth over $400 million. This project examines the possibility of using non-toxic food thickeners to prevent or reduce the intensity of future mudslides by increasing soil viscosity and decreasing the rate of mud flow, and increasing the amount of water needed for slope failure. Soil containing guar gum and whey protein, each at low and high concentrations, were investigated by determining the liquid limit, conducting SEM and rheology, and testing the toxicity. Throughout this project the engineering design process will be employed; beginning with this problem statement, finding solutions, implementing the solutions, and testing to determine if the solutions are applicable. This project may have significant positive economic, environmental, social, and global impacts.

1.1. Broader Impact

There are wide ranging economic effects that will occur as a result of discovering a method to thicken soil to mitigate the effects of mudslides. The Montecito mudslide resulted in $421 million in insurance claims, $338 million of which were listed as residential property losses, including over 100 homes destroyed. Vehicles and businesses were also heavily damaged.[1] Property owners' belongings were destroyed or they lost value, due to damage. Even if property owners received insurance, it is not likely that they received compensation for the full value of their losses. Therefore, preventing a mudslide saves money for property owners. Insurance companies would also save money because they would not have to fulfill claims.

The research and development of thickeners could also contribute to economic growth. Jobs would be created to research, manufacture, and distribute the thickeners. Additionally, research will also open the door for future innovation and research topics that are exposed by the development of soil thickeners. This will lead to long term positive effects on the economy. Mudslide prevention via soil thickeners has many potential economic benefits.

Thinking broadly, there may also be a positive economic outcome from mudslides. In the aftermath of a natural disaster, many industries are involved in the recovery effort. Construction, architecture, and engineering industries benefit from a mudslide because jobs are created in these sectors, stimulating the economy. Mudslide prevention might limit economic growth by removing opportunities for certain industries such as construction. However, while this is a potential risk of this project, the net economic benefits along with the social benefits outweigh this risk.

The main objective of this study is to find a non-toxic soil thickener that will have minimal environmental impact on the ecosystem of the affected area. Ecosystems have a delicate balance which could be disrupted by the introduction of small or large quantities of food thickeners. This issue is complex and could have unforeseen impacts on the local wildlife. Therefore, this project may be environmentally risky.

The social impacts of this project could be significantly beneficial. Landslides kill 25 to 50 people in the United States every year.[2] The Montecito mudslides killed 23 people.[1] The physical and emotional trauma can dramatically impact the community. Individuals must handle practical business matters such as food, savings, housing, and insurance claims, all while dealing with the trauma of losing friends, neighbors, or in some cases, family. Additionally, the trauma caused can have long term negative effects on individuals and the community. Preventing mudslides would be a great social benefit, that reduces emotional and physical trauma.

Since many countries are affected by mudslides more than the United States, this project could have a larger impact globally than locally. It is estimated that the global death toll of landslides is in the thousands each year.[3] While different countries and communities have varying customs and cultures, they would be affected in generally the same way as the Montecito community by a mudslide. There would be damage to homes, businesses, property, and possibly loss of life. Therefore, this project is even more significant globally than locally. Mitigating the effects of mudslides would lessen economic hardships, decrease damage to infrastructure and communities, stimulate scientific innovation, and save lives around the world. There are risks, such as unknown environmental impact, but the benefits outweigh the potential risks.

2. Background

2.1. Mudslide Background

This project was motivated by the Montecito, California mudslides which occurred after the Thomas fires in January 2018. In the event of a fire, the vegetation on the slope will be destroyed. Plants play a vital role in the stability of a slope; the roots absorb water and strengthen the soil by holding soil aggregates together and plant coverage on the slope helps to improve infiltration, and prevent runoff and ultimately erosion. Once the plants burn, the slope is exposed and becomes vulnerable to slope failure, causing mass wasting. The liquid limit of a soil, the moisture content at which a plastic soil transitions to liquid behavior, will be tested because a slope's probability of failure increases when it reaches or nears its liquid limit.[4]

2.2. Thickeners & Mechanisms

Hydrocolloids, a heterogeneous group of long chain polymers (polysaccharides and proteins) are used in many foods as thickening agents. They are many materials that form colloids in water, with a colloid being a homogeneous substance of one substance dispersed throughout a second substance. The hydrophilic nature of hydrocolloids along with their ability to produce colloids gives them their thickening properties. Thickening involves the non-specific entanglement of conformationally disordered polymer chains.[5] At a low concentration of thickener, the individual molecules of the hydrocolloids move freely and do not thicken. At and above a certain concentration C*, the polymer exhibits non-Newtonian behavior. The molecules come in contact, creating an entangled network that produces the thickening effect.

Starch is the most commonly used hydrocolloid thickener due to its abundance and low cost. In foods, it is usually used at a concentration of 2 to 5 wt%.[6] Cold water does not activate starch. Only heated water can penetrate starch, and cause it to swell up. Boiling water causes the granules to burst and release inner starch molecules which are free to interact with and trap water. While starch is an effective and common thickener, the need to be heated to activate thickening disqualifies it as a candidate for the soil thickening application.

Many gums are effective hydrocolloid thickeners. Guar gum disperses completely in hot or cold water due to its high galactose content, while locust bean gum requires heat. Viscosity is higher for guar gum than locust bean gum at the same percent solids due to the higher molecular weight of guar gum. Carboxymethyl cellulose is another thickening gum, and is soluble in both hot and cold water. Another, tragacanth gum, swells rapidly in both hot and cold water and forms viscous dispersions. Guar gum was ideal for this investigation because it is a commonly used, well known, and effective thickener. The vast number of hydrogen bonds in its structure hold on to water, increasing viscosity (Figure 1).

Whey protein is also useful as a thickener. Whey is a protein composed of many amino acids: beta-lactoglobulin, alpha-lacalbumin, serum albumin, lactoglobulins, and lactose. Proteins can also form hydrogen bonds, but not nearly as many as guar gum. Proteins hold water due to hydrophilic van der Waal's interactions. A beta-lactoglobulin model system, which accounts for about half of the protein in bovine whey isolate, revealed that at a critical concentration above approximately 7 wt%, this protein thickens by forming aggregates with strong interactions (Figure 2).[7] At pH 3.35, flexible fibrillar networks formed, although extensive details of the thickening mechanism are unknown.

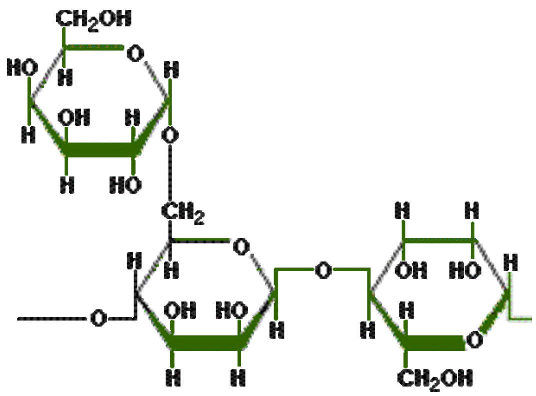


Figure 1. The chemical structure of guar gum, which contains many hydrogen bonds.

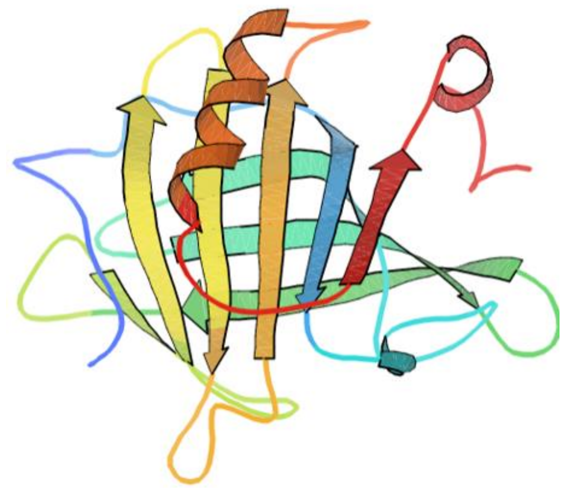


Figure 2. Biomolecular structure of beta-lactoglobulin. Ribbons denote the secondary structure (hydrogen bonds), with arrows for beta strands (extension of protein chain) and spirals for alpha-helices (amino acids).

2.3. Uses of Thickeners in Mud

Hydrocolloids are commonly used as mud thickeners in petroleum drilling operations. The mud is composed of mainly bentonite clay. Carboxymethyl cellulose and hydroxyethyl cellulose have become the industry standard thickeners. Other thickeners such as guar gum and starch are used as well. Research shows that welan gum increases mud viscosity more effectively than carboxymethyl cellulose.[8]

Chitosan is a high viscosity substance that has been investigated to improve earthen construction. It is a biopolymer derived from chitin, an abundant and natural polysaccharide. Structures made of earth are vulnerable to erosion and degradation from water exposure due to their porous and hydrophilic nature. The addition of chitosan has been shown to improve the mechanical properties and water resistance of earthen constructions.[9] The material became less water absorbent due to a hydrophobic barrier produced by the chitosan. The vulnerability of the chitosan-treated soil to water was measured using sessile drop contact angle measurements and drip erosion tests. When applied as a coating, a low chitosan concentration of 0.5% m/v was sufficient to repel water. When incorporated as an admixture, a chitosan concentration of at least 3% m/v was needed to be hydrophobic. Water drip erosion tests needed a chitosan concentration of at least 1% m/v to be effective.

2.3. Test Methods

The effectiveness of the soil thickeners can be measured using the liquidity index. The liquidity index is a strong indicator of the possibility of mudslides occurring due to the low viscosity of the soil. The liquidity index can be calculated from the Atterberg limits (Equation 1).[10]

$$LI = \frac{w - PL}{LL - PL} \tag{1}$$

where LI is the liquidity index, LL is the liquid limit, PL is the plastic limit, and w is the water content.[10]

One Atterberg limit, the liquid limit, is the upper bound of soil saturation before a soil transforms to liquid behavior. The liquid limit can be used as an indicator of the water content at which a mudslide may occur. However, depending on the severity of the slope, vegetation, or natural events such as earthquakes, mudslides can occur at a water content that is lower than the liquid limit.[10] Liquefaction can be induced in a soil in moisture contents as low as 85% of the soil's liquid limit, effectively causing a mudflow.[4]

The liquid limit can be determined with a Casagrande cup, a brass cup that rises and falls from a calibrated distance to strike the base of the testing device. Each time the cup falls, the soil, split in two, slides towards the middle (Figure 3). Although simple and straightforward, the Casagrande cup test is flawed because it measures the dynamic motion of the soil; additionally, the Casagrande cup test does not evaluate any time-dependent polymeric reactions taking place in the soil. There is a more accurate, quasi-static, testing procedure available called the falling cone test. However, when both are performed accurately, the quasi-static falling cone test and the Casagrande cup report values within an error of 1% of each other. Despite the Casagrande cup test being slightly more variable, the Casagrande cup test is used almost exclusively in the United States to determine the liquid limit of soils.[11]

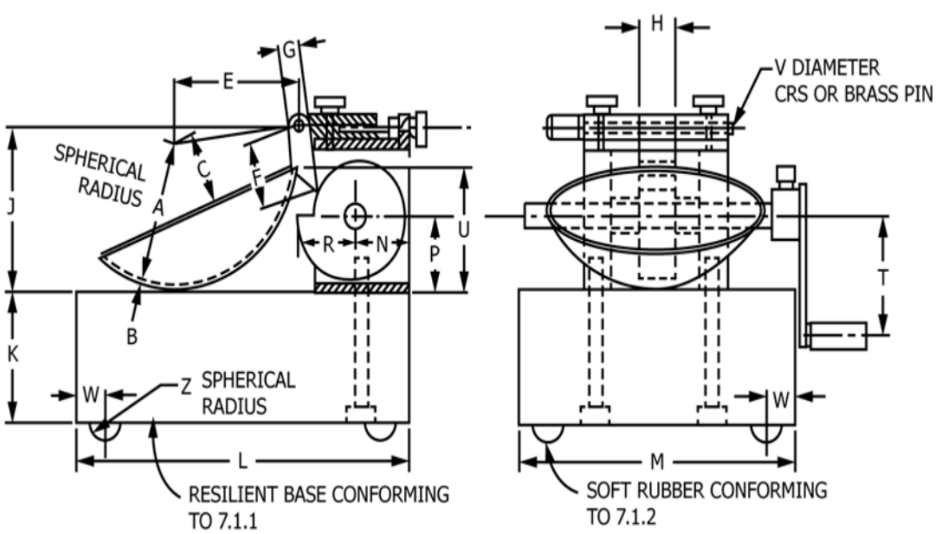
(a)

DIMENSIONS

LETTER	A^{Δ}	B^{Δ}	C^{Δ}	E^{Δ}	F	G	H	J^{Δ}	K^{Δ}	L^{Δ}	M^{Δ}
MM	54 ± 0.5	2 ± 0.1	27 ± 0.5	56 ± 2.0	32	10	16	60 ± 1.0	50 ± 2.0	150 ± 2.0	125 ± 2.0

LETTER	N	P	R	T	U^{Δ}	V	W	Z
MM	24	28	24	45	47 ± 1.0	3.8	13	6.5

$^{\Delta}$ESSENTIAL DIMENSIONS



CAM ANGLE DEGREES	CAM RADIUS
0	0.742 R
30	0.753 R
60	0.764 R
90	0.773 R
120	0.784 R
150	0.796 R
180	0.818 R
210	0.854 R
240	0.901 R
270	0.945 R
300	0.974 R
330	0.995 R
360	1.000 R

FIG. 1 Hand-Operated Liquid Limit Device

(b)

Figure 3. (a) A finished Casagrande cup test where the two halves of the soil have slid to the center and closed the middle groove. (b) A schematic of the Casagrande Cup as specified by ASTM D4318-17.

The falling cone test can also be used to determine the plastic limit of the soil, where the plastic limit is the moisture content of the soil at the transition point between plastic behavior and semi-solid behavior.[12] The falling cone test is often more reliable, due to less variation than the standard rolling test. The rolling test, widely used in the United States, is more variable as it is dependent on the operator's skill. The rolling plastic limit test involves the operator attempting to roll a soil sample between the palms of their hands into a cylindrical thread of soil ⅛ inch in diameter, unless the water content is reached at which the soil crumbles before reaching the minimum diameter of ⅛ inch. The results from the rolling plastic limit test are less reproducible; however, the rolling test is still used as the industry standard in the United States because it is approximately correct and is quick and inexpensive (and often fun) to perform.[12]

Another alternative to using the liquidity index, traditional Casagrande cup test, and rolling plastic limit test is the flow box. The flow box was invented by soil scientists Budijanto Widjaja and Shannon Hsien-Heng Lee. The flow box uses a piston trap-door system to measure soil viscosity changes as the soil changes from a plastic state to a state of low viscosity (Figure 4). Using the flow box the soil scientists were able to measure viscosity as a function of water content, and study other factors that contribute to a mudslide initiation.[10]

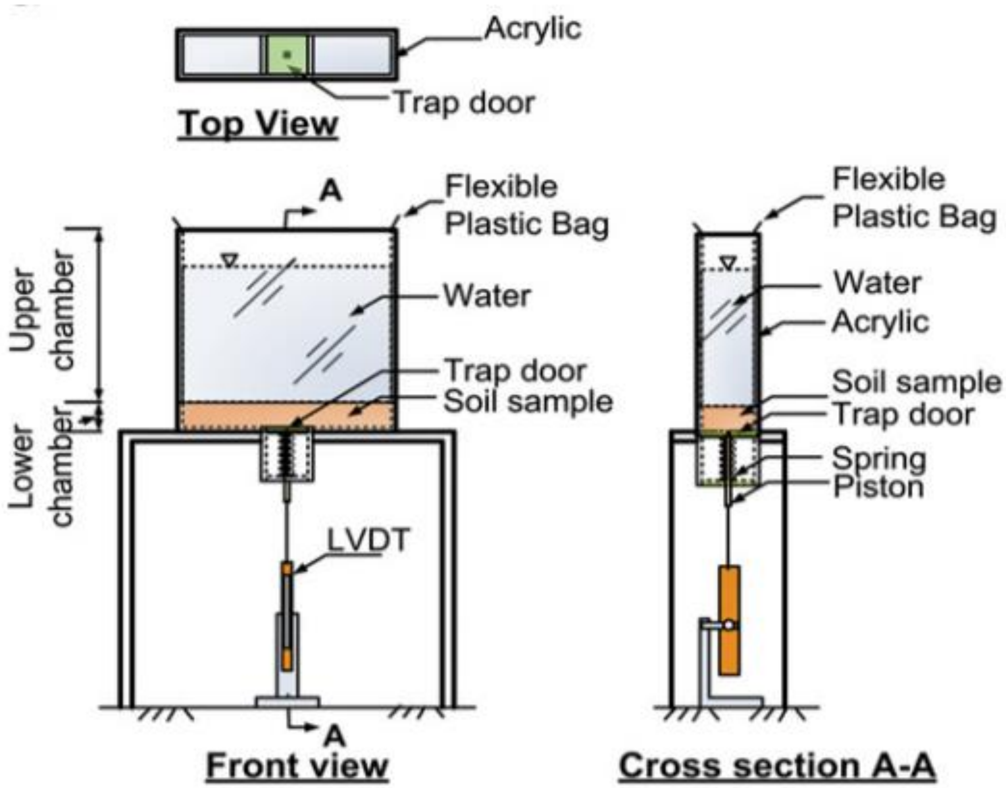


Figure 4. The soil flow box designed by soil scientists Budijanto Widjaja and Shannon Hsien-Heng Lee.[10]

3. Materials & Methods

For this project, four mixtures of thickeners and soil were tested using mechanical testing, chemical testing, and imaging.

3.1 Materials

3.1.1 Soil

20 gallons of soil were obtained from the hills behind the Fremont dorm on the Cal Poly campus. A mudslide occurred in this area in February 2017 from heavy rainfall. The soil in this area is ideal for testing, in part because of the history of mudslides, but also due to the high content of clay, which contributes to failure. The soil is a Fat Clay (CH), as classified by the Unified Soil Classification System. Fat clays are fine grained soils where 50% or more can pass through a No. 200 sieve (0.075 mm). Weighing wet soil before and after drying for 24 hours in a 42°C oven indicated that the soil was 20.88 wt% water. Throughout the experiment the wet untreated soil was kept in sealed 5 gallon plastic buckets to maintain a constant moisture level.

3.1.2 Thickeners

The purpose of this project is to evaluate the ability of various thickeners to increase the viscosity of soil. The factors studied were the thickener type and thickener concentration. The two thickeners, guar gum and whey protein, were evaluated at a low and a high concentration. Guar gum was chosen because many food industry thickeners are gums, and it is a well known, common, and effective thickener that is easy to obtain. Whey protein was chosen because it has a different thickening mechanism than guar gum, and is a well known food product that is also easy to obtain. Guar gum was purchased from Bob's Red Mill, and 100% whey protein powder was purchased from and manufactured by Nuts.com. The low and high concentrations studied for guar gum were 1 wt% and 10 wt%, respectively, of the 20.88 wt% moisture content of the soil. Likewise, the low and high concentrations studied for whey protein were 2 wt% and 19 wt%, respectively, of the 20.88 wt% moisture density in the soil. The low concentrations were based on numbers used in the food industry and seen in food science-related literature. The high concentrations represent an extreme because of the difference in properties between soil and foods such as soups where thickeners are often used. The high concentration is meant to try to provide clear results in the event that the low concentrations fail to provide observable information.

3.2 Methods

3.2.1 Mixing Soil and Thickeners

An Avantco MX10 mixer was used to mix each thickener into the soil. Roughly 1900 grams of soil was weighed out for each batch (based on the mixer capacity and power), and mixed with the appropriate amount of thickener. The weight percent of thickener is based on the weight of water in the soil. Using the measured moisture level of the soil of 20.88 wt% water, the percentages of thickener (1 wt% of water content and 10 wt% of water content for guar gum, and 2 wt% of water content and 19 wt% of water content for whey protein) were calculated. The soil and thickeners were combined in the mixer bowl and mixed using the cast aluminum dough beater attachment on the low speed setting. For the 1 wt% guar gum and 2 wt% whey protein samples, the mixer was run for about 10 seconds, or until the thickener was no longer easily visible. Mixing too long caused the moist, clay-like soil to clump together and become difficult to manage. For the 19 wt% whey protein sample, the mixer was run for about 20 seconds, or until the thickener was no longer easily visible. For the 10 wt% guar gum, the thickener was run for about 30 seconds. However, the thickener remained visible in the 10 wt% guar gum. The mixed soils were stored in buckets with the lid closed to maintain a constant moisture level (Figure 5). The soils mixed with high concentrations of whey protein and guar gum resulted in soil that was more broken up because they absorbed water and decreased clumping during mixing.

3.2.2 Liquid Limit

The Casagrande cup test was used to determine the liquid limit following ASTM D4318-17e1. Approximately 700 grams of each of the five soil types (untreated control, low concentration guar gum, high concentration guar gum, low concentration whey protein, high concentration whey protein) were oven-dried at 42°C for 24 hours. The oven-dried samples were broken apart using a mortar and pestle. Then 500 grams of each of the dried soil types were passed through a No. 35 sieve, resulting in fine-grained samples consisting of particles less than or equal to 0.5 millimeters in diameter. The test was then run according to the ASTM standard.

3.2.3 Rheology

Rheology was performed on untreated and treated soil samples using a BYK-Gardner KU-1+ Viscometer (Figure 6). Viscosity was measured in Krebs units (KU), which is the weight in grams applied to paddle-type rotor submerged in the sample that will allow it to turn 100 revolutions in 30 seconds. It is used primarily for evaluating the viscosity of formulated paint and coating materials.

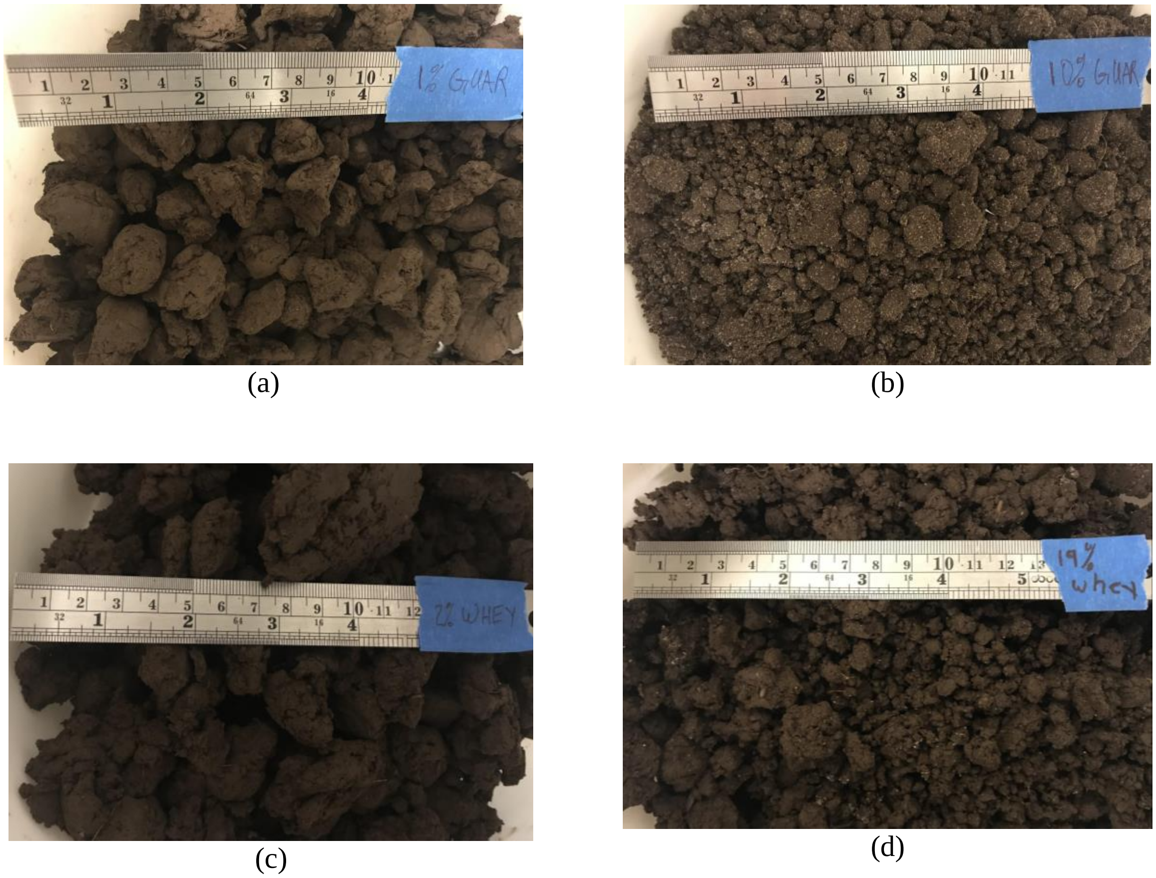


Figure 5. (a) Soil mixed with 1 wt% guar gum. (b) Soil mixed with 10 wt% guar gum. (c) Soil mixed with 2 wt% whey protein. (d) Soil mixed with 19 wt% whey protein.

For each soil sample, 130 grams of the sample was mixed with 150 grams of water in a pint-sized epoxy-lined paint can. Mixing was done vigorously and thoroughly by hand with a micro spatula in circular motions for 30 seconds. Immediately after mixing the viscosity was measured using the Viscometer, and the range of values were recorded. The paint cans containing the soil samples were sealed with a lid and left untouched for 72 hours in a drawer at room temperature. After 72 hours the paint cans were opened and each sample was mixed by hand again for 30 seconds before measuring the viscosity. This was done to see the effect of time on the thickeners' abilities to increase soil viscosity.

Figure 6. A viscometer similar to the model used. The paddles are shown above the paint can.

3.2.4 Scanning Electron Microscopy (SEM)

Initially, light microscopy was attempted to examine the soil samples. However, the uneven surfaces of the samples produced poor, unfocused images. Even after compressing the soil between glass microscope slides in an attempt to flatten the surface resulted in poor, unusable images. Therefore scanning electron microscopy was used to examine microstructural changes in the thickener-treated soils. Samples were prepared by mixing a small amount of soil with enough water to saturate the soil, and then rolling the wet soil between one's palms to form a ball roughly 1 cm in diameter. The ball was broken in half by manually pulling it apart to create a fracture surface, with care not to touch the fracture surface (Figure 7). The samples were then dried for 24 hours at 42°C. The samples were mounted using copper tape and gold sputter coated prior to insertion into the SEM. Secondary electron and backscattered electron images of the samples were taken at 20X, 500X, 1000X, 3000X, and 6000X magnifications.

Figure 7. Soil samples prepared for SEM. Each soil sample is mounted on an aluminum SEM stub measuring approximately 0.5" in diameter.

3.2.5 Toxicity

Annual ryegrass seeds were potted in each of the untreated and treated soils to determine the effect of thickeners on local vegetation. This grass was chosen because it is commonly used as a cover crop and as an ornamental grass, and is a native species of vegetation in California. Each soil treatment was potted into four 16 oz. pots, for a total of 20 pots. 30 grass seeds were evenly sprinkled on the top layer of soil in each pot. The pots were watered by misters over 15 minutes, 3 times a day (morning, noon, and evening). For four weeks, additional unknown amounts of water were added to the pots by an unknown greenhouse user, which improved the growth rate of the ryegrass. The ryegrass from each pot was clipped 6 weeks after the start of germination, resulting in a total of 20 samples. The freshly clipped ryegrass was weighed in a 100 mL glass beaker using a digital scale. The freshly cut ryegrass was then oven-dried at 60°C for 24 hours, and placed in a desiccator afterwards to avoid the dry grass from absorbing moisture from the air (Figure 8). Biomass measurements were made by weighing the oven-dried ryegrass on an analytical scale capable of measuring mass to the thousandths of grams. Biomass is used as a measure of the toxicity of the soil thickening treatment, as biomass is expected to correlate with the health of the ryegrass.

Figure 8. Desiccator with 20 oven-dried ryegrass samples.

A Milwaukee MA871 Digital Brix Refractometer was used to measure the sugar content of the liquid in the blades of ryegrass; the sugar content is used as a proxy for quantifying the toxicity of the soil thickening treatments (Figure 9). The sugar content will indicate the health of the ryegrass, with healthier grasses producing more sugar. One gram of blue ryegrass seeds was sprinkled on the top layer of four pots in each soil treatment to provide ryegrass samples for the Degrees Brix (°Bx) measurement. The °Bx measures the soluble solids content of a liquid. One °Bx corresponds to approximately one gram of sucrose in 100 grams of solution. If the solution contains solids other than sucrose, then °Bx measures the soluble solids content. The approximation that sucrose comprises most of the soluble solids in grass is made here.

Three weeks after germination, the ryegrass was harvested from each sample pot. A garlic press was used to squeeze the liquid out of the ryegrass samples. The refractometer was calibrated using distilled water, and an average of five drops of liquid from each ryegrass sample was put into the prism well in order to ensure full coverage of the prism. In order to accurately and consistently measure the sugar content, ambient light was blocked out by manually shielding the refractometer because the test was conducted in a bright room.

(a) (b)

Figure 9. (a) A garlic press was used to press liquid from the ryegrass. (b) Liquid was pressed until the well of the refractometer was filled.

4. Results and Discussion

4.1. Casagrande Cup Testing

The liquid limits found by Casagrande cup test were used to compare the amount that each soil treatment changed the water absorptivity of the soil. The liquid limit of the control sample was found to be 32 wt%

moisture content. All four of the soil treatments were found to raise the liquid limit of the soil. The soil treated with 2 wt% whey protein raised the liquid limit to 35.5 wt% moisture content. The 19 wt% soil treatment raised the soil's liquid limit to 42 wt% moisture content. The 1 wt% guar gum soil treatment raised the liquid limit to a moisture content of 37 wt%. The largest increase was from the 10 wt% guar gum soil treatment, which raised the liquid limit to 60 wt% moisture content. The compositions of the soils were then compared in order to evaluate the change in water absorptivity using a weight ratio of water to soil (Figure 10).

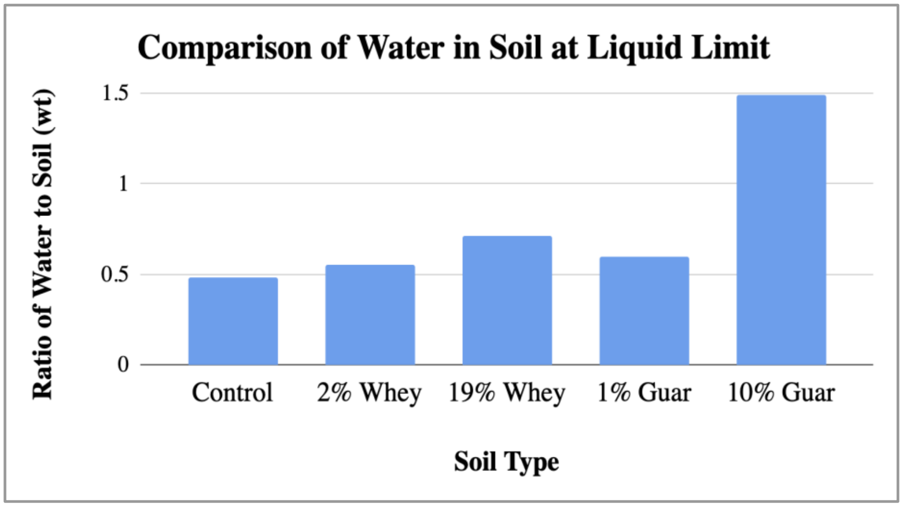


Figure 10. Comparison of the ratio of water to soil by weight between soil treatments at their liquid limit.

Each of the soil treatments raised the liquid limit of the soil above the liquid limit of the control sample; however, the soil treated with 10 wt% guar gum was able to hold 150% of its own weight in water. Guar gum's ability to hold water using hydrogen bonds causes a large change in water absorptivity in the 10 wt% guar gum sample. Additionally, the guar gum forms a structure inside the soil by dissolving into hydrocolloids that bond with one another. The internal structure strengthens the soil, and effectively holds water within the soil.

4.2. Rheology Testing

Results from viscosity testing showed the differences in thickening effect for the different thickeners, and the effect of time on thickening ability (Figure 11). The viscosity reading shown by the viscometer represents a range of values that were observed over a period of 10 seconds. The instrument updates the viscosity reading multiple times a second, resulting in a range of values. Some of the ranges were wider than expected, such as the initial viscosity of the control which ranged from 69-74 KU. This wide range is likely due to the large particle sizes of the soil which the instrument was not meant to handle. The particle sizes of paints and coatings are typically less than 100 microns, while the No. 35 sieve that was used resulted in particle sizes less than 500 microns. This is a significantly larger particle size. Additionally, mud does not stay dispersed and instead settles. This contributes to the relatively large range in viscosity readings.

The untreated control soil initially had a relatively low viscosity of about 70 KU, with a small increase of about 10 KU after 72 hours. The increase after 72 hours is likely due to the natural polymers found in the clay soil which had time to interact with the water, forming bonds and inhibiting movement.

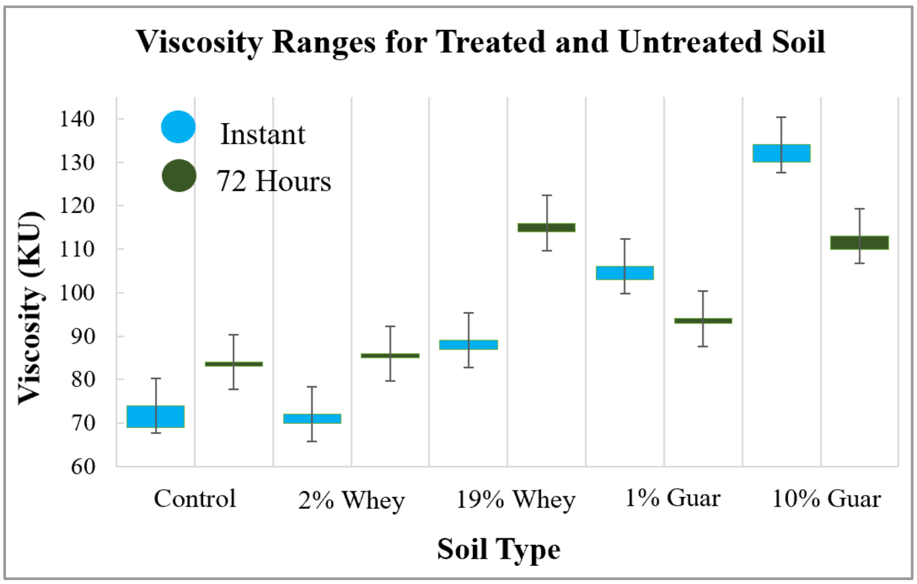


Figure 11. Viscosity for soils, instantly after mixing and 72 hours after mixing.

The viscosity of the 2 wt% whey protein sample was not significantly different from the control soil both instantly and 72 hours after mixing. The 19 wt% whey protein sample, however, had an increased initial viscosity by about 15 KU in comparison to the 2 wt% whey protein sample, and a greater viscosity increase of about 30 KU 72 hours after mixing. The high initial viscosity can be explained by the immediate thickening effects of whey protein. Van der Waals interactions occur between the thickener and water, inhibiting movement of chains. As time passes, it is likely that the proteins are becoming denatured. Their original structure that resembled a tight, tangled ball of amino acid chains becomes unfurled, leaving more surface area for interactions between the whey and water. This may explain the large jump in viscosity.

The 1% guar gum had a higher initial viscosity than even the 19 wt% whey protein sample, which was surprising because of the low amount of guar gum thickener used. However, guar gum is known to be very effective in food thickening applications. Its many hydrogen bonds are attracted to and hold on to water, creating an entangled network of polymer chains that inhibit movement. 72 hours after mixing, the viscosity decreased by about 10 KU. This is likely because the microbes in the soil are degrading the thickener over time. This effect can be seen more obviously in the 10 wt% guar gum sample, which had an extremely high initial viscosity of about 135 KU. 72 hours after mixing, its viscosity decreased to about 110 KU. There is a more significant decrease in viscosity with more thickener because there is more thickener available to be degraded by microbes. Even though the 10 wt% guar gum sample experienced a significant decrease in thickening ability over time, the decreased viscosity was still just as high as the greatest viscosity value for soil samples containing whey protein as a thickener.

4.3. SEM

Examination of the untreated control soil sample was attempted using the SEM to reveal the structure of soil particles. The SEM images of the control sample were to provide a baseline of what soil particles look like for future SEM imaging of guar gum- and whey protein-thickened soil samples. However, the non-conductive nature of the soil caused a charge to build up during imaging, preventing clear images from being obtained (Figure 12).

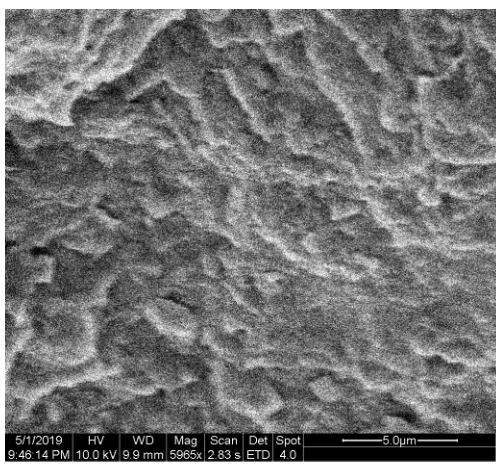
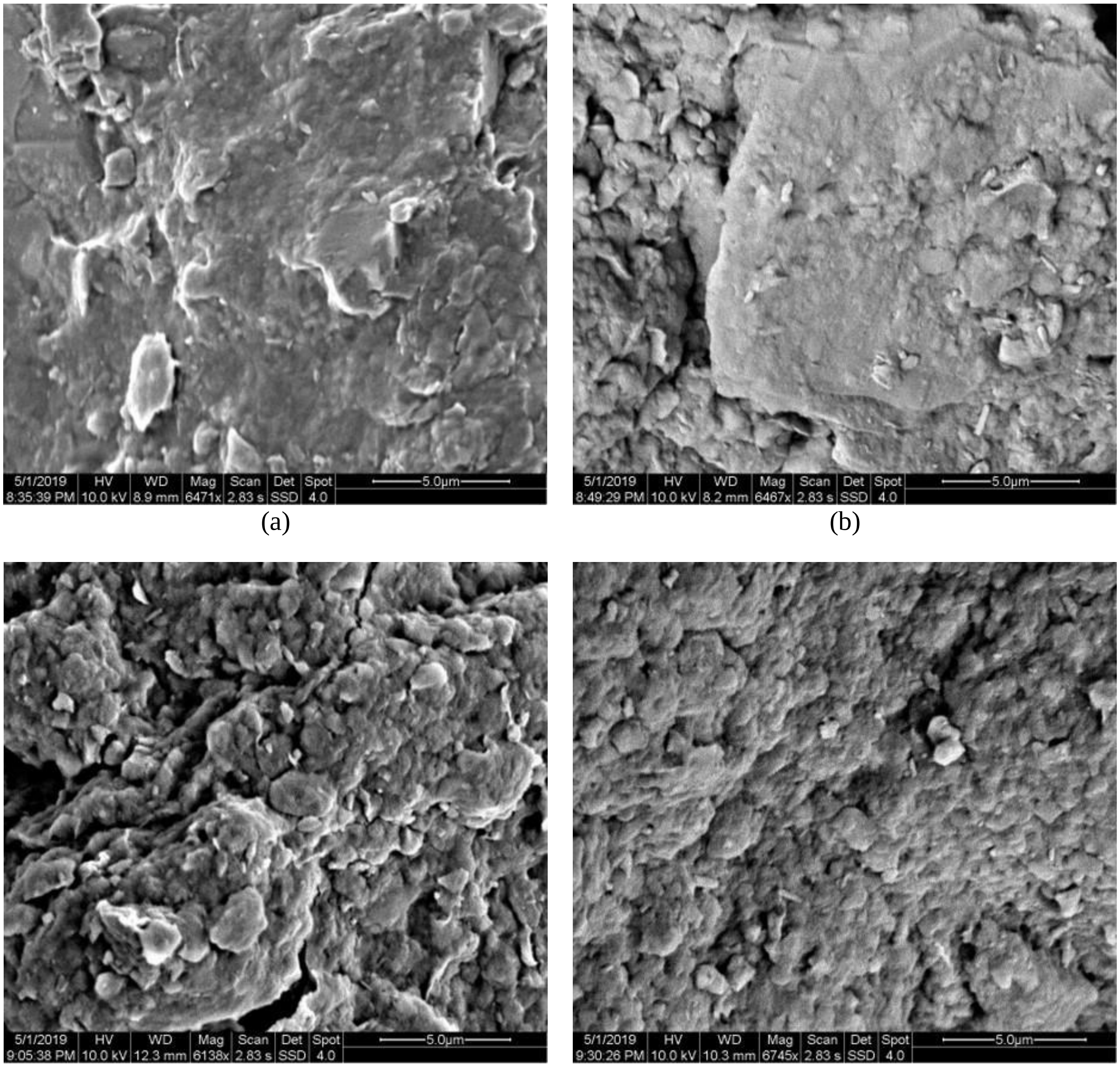


Figure 12. SEM secondary electron image of untreated soil. Quality is poor due to charge build-up.

SEM imaging was taken of the fracture surfaces of each soil treatment (Figure 13). While these samples were sputter coated, it was still difficult to obtain high magnification images. Ultimately, these images are not conclusive, but may indicate a relationship between the thickener concentration and surface energy. The fracture surfaces of the low concentration samples (Figures 13a and 13c) show sharp features, while the fracture surfaces of the high concentration samples (Figures 13b and 13d) show similar features that appear to be rounded or filled in, possibly due to increased surface energy due to the high concentration of thickeners.



(a) (b) (c) (d)

Figure 13. SEM backscattered electron images of soils. (a) Soil treated with 2 wt% whey protein. (b) Soil treated with 19 wt% whey protein. (c) Soil treated with 10 wt% guar gum. (d) Soil treated with 1 wt% guar gum.

4.4. Toxicity Testing

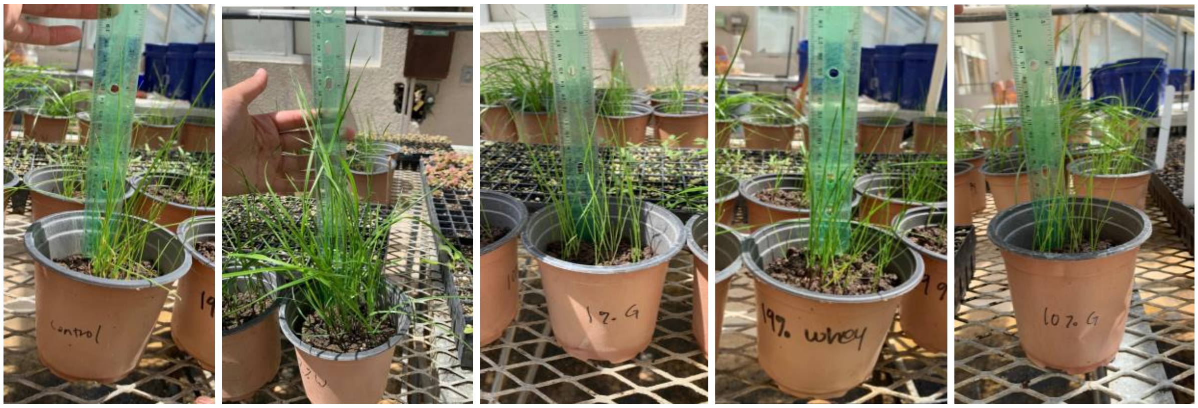
After three weeks, the annual ryegrass seeds germinated and grew in every soil treatment (including the untreated control sample) except for the pots with 19 wt% whey protein-treated soil (Figure 14). The four control ryegrass samples had an average length of 5 cm. Ryegrass grew in pots containing soil treated with 2 wt% whey protein; however each pot did not have a consistent number of blades. The average blade length was 4 cm for the ryegrass grown in pots containing soil treated with 2 wt% whey protein. Only 3 out of 4 of the pots containing 10 wt% guar gum-treated soil grew one 3.5 cm blade each. Similarly, 3 out of 4 of the pots containing 1 wt% guar gum-treated soil grew around 3 blades of ryegrass having an average length of 3 cm.

(a) (b) (c) (d) (e)

Figure 14. Ryegrass growth after 3 weeks. (a) Untreated soil. (b) Soil treated with 2 wt% whey protein. (c) Soil treated with 19 wt% whey protein. (d) Soil treated with 10 wt% guar gum. (e) Soil treated with 1 wt% guar gum.

After 6 weeks, the annual ryegrass grew in all soil thickener treatments (Figure 15). Visually, the ryegrass that grew in the soil treated with 2 wt% whey protein was significantly thicker and fuller with more blades of grass (an average of 20 blades per pot) than any other treatment. This may be due in part to the fact that whey protein is often used as a plant fertilizer. Additionally, ryegrass grown in pots containing the 2 wt% whey protein-treated soil had an average height of 20 cm, taller than any other treatment. Although the number of blades for all treatments were comparable in terms of number of blades per pot (15 blades on average), there was some variance in ryegrass height for each of the treatments. The ryegrass grown in pots containing soil treated with 1% guar gum grew an average of 11 cm, ryegrass grown in the control pots grew an average of 10 cm, and ryegrass grown in pots containing soil treated with 10 wt% guar gum and with 19 wt% whey protein each grew an average of 9 cm.

Ryegrass grown in each of the guar gum-treated samples and the 19 wt% whey-treated sample showed no significant difference in biomass in comparison to ryegrass grown in untreated soil, suggesting that these thickening treatments are non-toxic (Figure 16).



(a) (b) (c) (d) (e)

Figure 15. Ryegrass growth after 6 weeks. (a) Untreated soil. (b) Soil treated with 2 wt% whey protein. (c) Soil treated with 19 wt% whey protein. (d) Soil treated with 10 wt% guar gum. (e) Soil treated with 1 wt% guar gum.

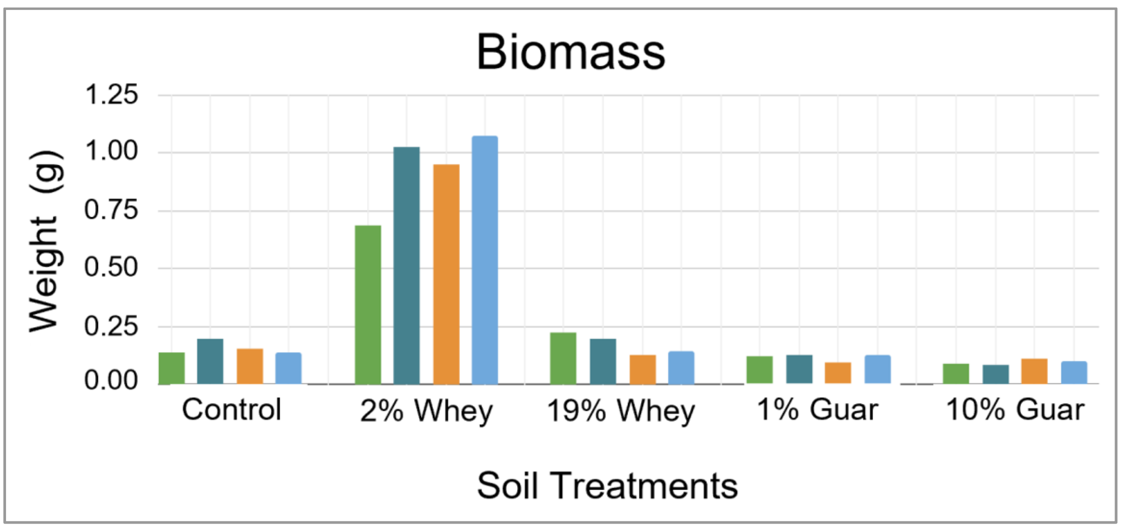


Figure 16. Biomass of ryegrass grown in treated and untreated soils.

Ryegrass grown in 2 wt% whey-treated soil showed an increased biomass which can be explained by the use of whey (in low concentrations) as a fertilizer due to its nitrogen and phosphorous content. ANOVA one-way analysis with the Tukey method showed that only 2 wt% whey treatment had significantly different results (Figure 17). The most desirable effect of the thickeners is to have no effect on the ryegrass. Any effect, even a fertilizing effect, may disrupt the natural balance of various ecosystems. Therefore 2% whey is non-toxic, but still not ideal for this soil thickening application.

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping	
2 W	4	934.0	A	
19 W	4	173.2		B
Control	4	157.6		B
1 G	4	119.32		B
10 G	4	98.67		B

Means that do not share a letter are significantly different.

Figure 17. One-way ANOVA test showing that only the 2 wt% whey-treated soil had a significantly different biomass.

Brix testing did not indicate a clear difference in the °Bx for ryegrass grown in soils treated with a thickener (Table I). The average °Bx is about 2 for all the samples, and there was a large amount of deviation within samples of the same soil treatment. From the results of this testing, no statistically significant change in °Bx was observed between soil treatments.

Table I. °Bx Results for Ryegrass Grown in Treated and Untreated Soils

	Control	2% Whey	19% Whey	1% Guar	10% Guar
Average °Bx	2.3	1.53	2.08	2.28	2.38
Standard Deviation	0.66	0.36	0.60	0.29	0.63
Range °Bx	1.7-3.3	0.9-1.8	1.6-3.1	2.0-2.7	1.8-3.4

4.5. Fungal Growth

Initially during the experiments, mold growth in the buckets containing moist soil was an issue. Soil mixed with guar gum and whey protein were left in sealed buckets, resulting in a dark, humid environment which enhances the growth of mold. This was a more significant problem for the whey protein-treated soils than the guar gum-treated soils; the fungal growth was also more significant in the higher concentrations of thickeners. For example, it might take under a week to produce visible mold growth in a bucket with whey protein-treated soil while it could take a few weeks for the guar gum-treated soil to visibly mold. The guar gum-treated soils experienced less fungal growth likely because it is a more effective thickener due to the strong hydrogen bonds it forms with water molecules, holding onto water and leaving less water available for fungi and microbes. Whey protein on the other hand relies on weaker van der Waals bonds that don’t hold as much water, leaving excess water in the soil that supports fungus and microbial growth. Additionally, the whey protein acts as a food source for the fungi. This mold issue was resolved by mixing fresh soil samples within a few hours of when they would be used. Any sample that molded was not used in this project; a new sample was mixed and used immediately.

5. Conclusions

The liquid limit of the control sample was found to be 32 wt% moisture content. All four of the soil treatments were found to raise the liquid limit of the soil, with the largest increase from the 10 wt% guar gum soil treatment, which raised the liquid limit to 60 wt% moisture content. Rheology showed that higher concentrations of whey protein cause a delayed thickening effect, where there is an instant thickening effect upon mixing, and after 72 hours there is an increase in viscosity. Guar gum has a greater initial thickening effect, and after 72 hours thickening decreases. 10 wt% guar gum had the greatest initial thickening effect, and the decreased viscosity of the soil after 72 hours was similar to the initial viscosity of the soil with 19 wt% whey. In terms of toxicity, all of the thickener treatments appear to be non-toxic to the annual ryegrass that was grown in them. Among the thickener treatments studied, the 2 wt% whey protein treatment resulted in thicker, fuller grasses with the highest average biomass and significantly higher average water weights, due to an unintended and undesirable fertilizing effect. The use of non-toxic food-thickeners in soil will increase the viscosity of soil and ability to absorb water. This will increase the amount of time it takes for a slope to fail in the event of mudslides, and decrease the rate of mud flow, possibly mitigating the effects of mudslides by giving people more time and lessening the impact.

6. Recommendations

For future work, it is recommended that alternative food thickeners be examined, in addition to other concentrations to optimize performance of thickeners. It is also recommended that a non-toxic biocide be used for preventing mold growth in the samples, as well as limit microbial interaction with the thickeners. It is also recommended that alternative testing methods be found or designed to better simulate a mudslide, such as the flow box previously discussed in the background. Additionally, samples for SEM should be prepared to allow more even sputter coating and higher quality images.

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